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System of System Management Strategy Impacts on SoS Engineering Effort

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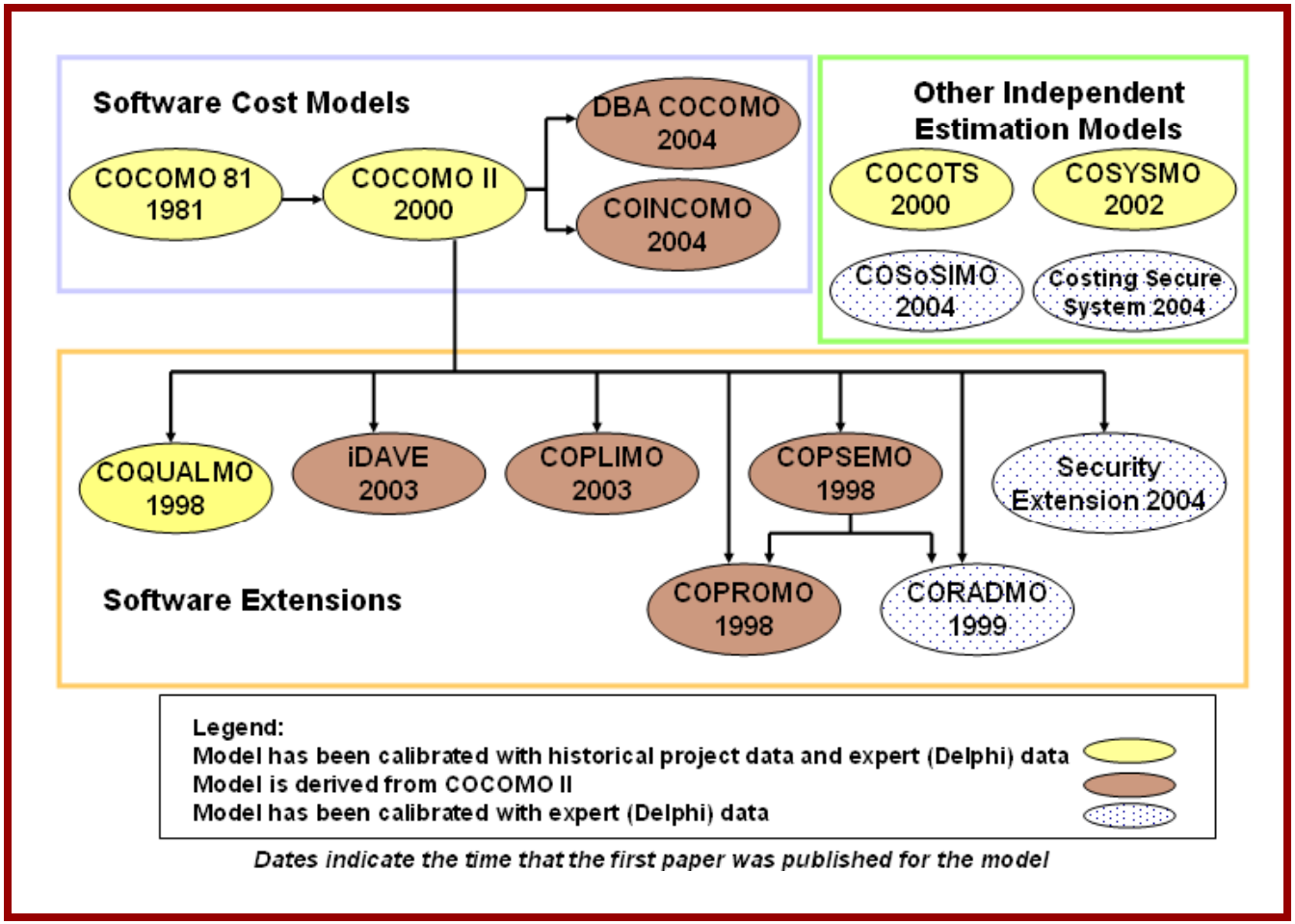
For further information, see PhD dissertation at
http://csse.usc.edu/csse/TECHRPTS/PhD_Dissertations/files/Lane_Dissertation.pdf

Overview

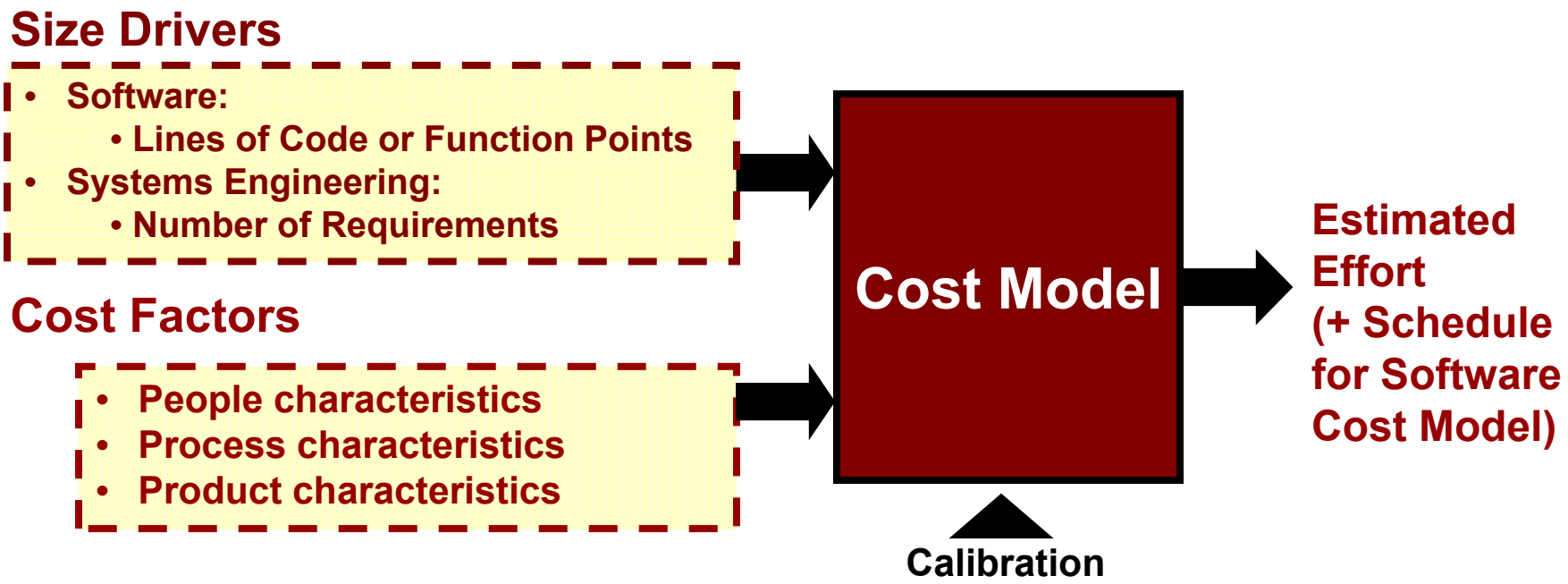
- Key definitions
- Scope of research
- Methodology
- Model implementation
- Results of research
- Conclusions and future work

COCOMO Cost Model Suite Overview*



* Barry Boehm, Ricardo Valerdi, Jo Ann Lane, and Winsor Brown, "COCOMO Suite Methodology and Evolution", *CrossTalk*, April 2005.

Engineering Cost Model Overview



General Form of Model Equation

Effort (person months) = $A * EM * (size)^B$

where A and B are calibration constants and EM (effort multiplier) is the composite cost factor

What is a "System of Systems"?

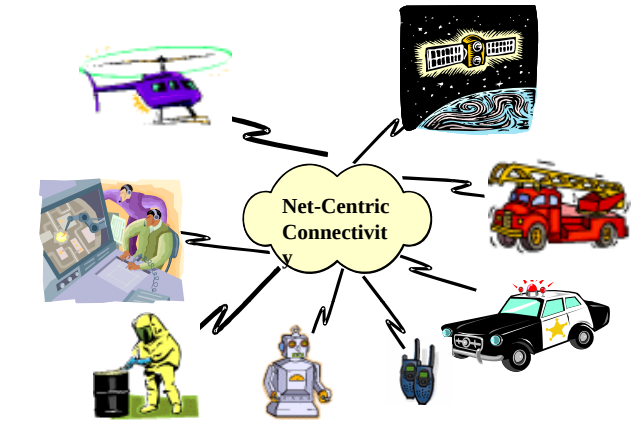
Development by composition

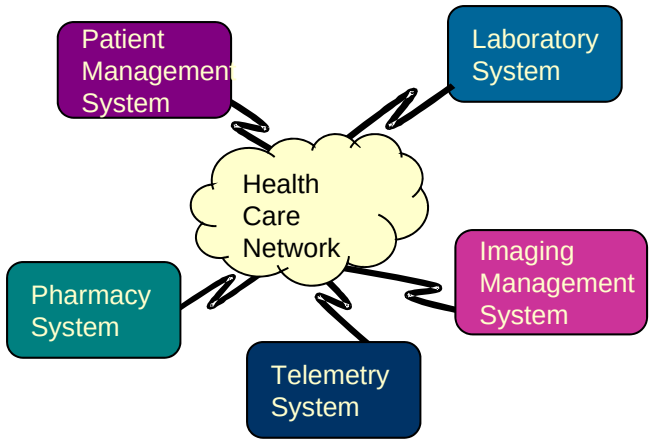
Independent evolution of constituents

Exhibits emergent behavior

Typical domains

- Military: Dynamic communications infrastructure
- Business: Enterprise-wide and cross-enterprise integration





Based on Mark Maier's SoS definition [Maier, 1998]

SoSE Compared to Classic SE Activities: Reported Differences

Architecting

- Architecting composability vs. decomposition
- Net-friendly vs. hierarchical

Prototypes/experimentation/tradeoffs

- Early tradeoffs/evaluations of alternatives
- Intense concept phase analysis followed by continuous anticipation; aided by ongoing experimentation
- Modeling and simulation, in particular to better understand "emergent behaviors"
- First order tradeoffs above the component systems level
- Discovery and application of convergence protocols

SoSE Compared to Classic SE Activities: Reported Differences *(continued)*

Scope and performance

- Added “ilities” such as flexibility, adaptability, composability
- Human as part of the SoS
- Organizational scope defined at runtime instead of at system development time
- Dynamic reconfiguration of architecture as needs change

Maintenance and evolution

- Component systems separately acquired and continue to be managed as independent systems

SoSE Compared to Traditional SE Activities: Key Challenges for SoSE

People

- Business model/incentives to encourage working together
- Removing multiple decision making layers
- Requiring accountability at the enterprise level

Process

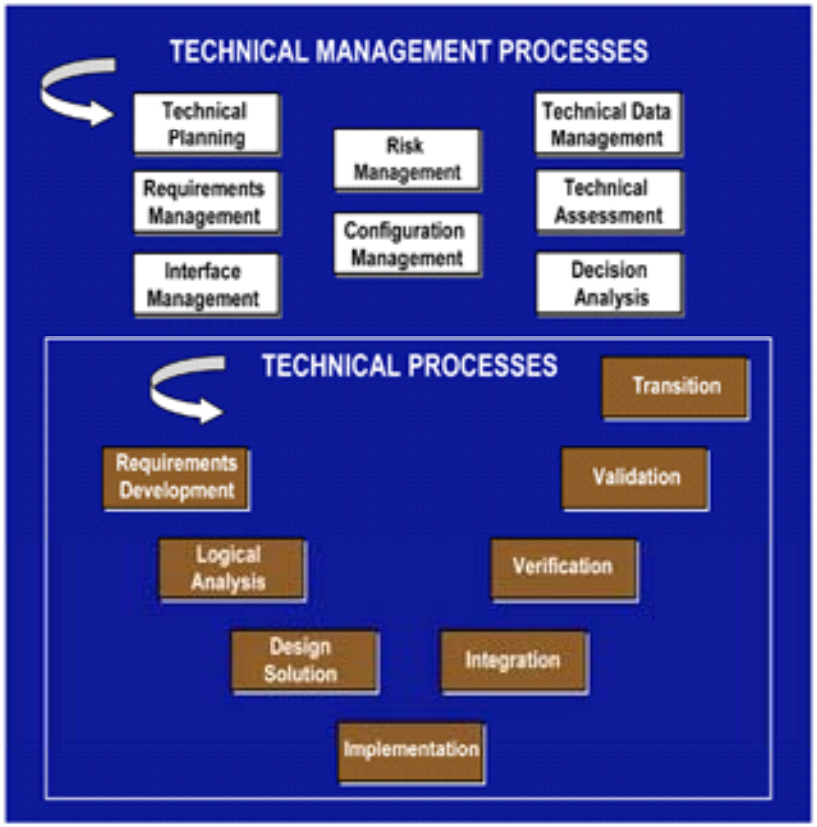
- Doing the necessary tradeoffs at the SoS level
- Human-system integration

Technical

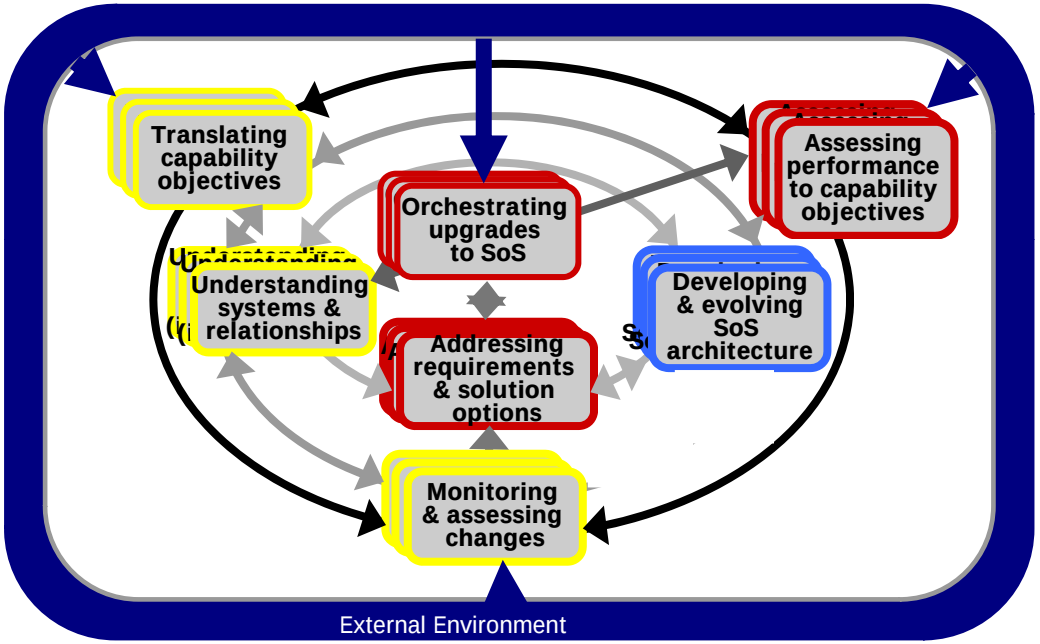
- Interoperability at the SoS level
  - Data, architecture, business strategies
- Evolution management
- Maturity of technology

For the most part, SoSE appears to be SE+

Classical SE and SoSE Activities



Traditional SE
(Defense Acquisition Guide [DoD, 2006] View)

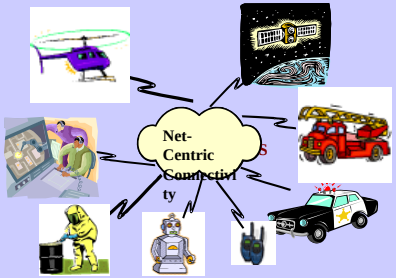


SoSE
(SoS SE Guidebook View Based on Interviews and Analysis of 18 DoD SoSs in Various Stages)

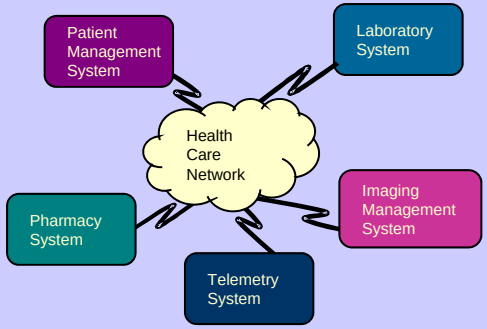
SoS Taxonomy

Internet

Virtual [Maier, 1998]



Collaborative [Maier, 1998]



Acknowledged [Dahmann, 2008]

Future Combat Systems

Directed [Maier, 2008]

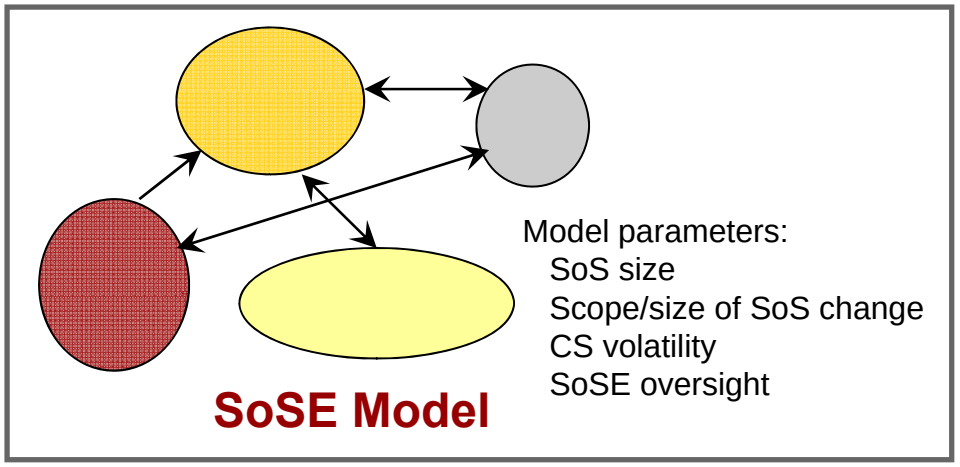
* Focus of this research effort

Initial Purpose of SoSE Model

Question: When is it cost effective to create and empower an SoSE team to oversee and guide the evolution of an SoS?

Primary hypothesis:

- There exists a threshold where it is more cost effective to manage and engineer changes to an SoS using an SoSE team
- Threshold can be determined by modeling the SoS interdependency and complexity characteristics.



Based on software-intensive SoSs owned by the US DoD

Purpose of Model *(continued)*

Provide:

- Guidance on the management of inter-related systems
- A method for conducting capability trade-off analyses
- A model that can evolve into an SoSE cost model through local calibration
- A better cost model for complex systems

SoSE Cost Model Approach

Using COSYSMO, developed a process model that can compare the SoS management strategies as SoS characteristics are varied

- SoS size (number of constituent systems)
- Size of SoS capability (number of equivalent nominal requirements)
- Scope of SoS capability (number of constituent systems affected by SoS capability)
- Constituent system volatility (level of constituent system change being engineered at the same time as SoS capability)

Process model based on data from

- 18 large-scale DoD SoS programs
- 16 DoD systems that participate as constituent systems in one or more SoSs

Analyze model outputs to determine under what conditions an SoSE team is cost effective

SoSE Model Overview

Model approach

- Estimate and compare the effort required to implement an SoS capability using two different management strategies
  - Collaborative (no SoSE team)
  - Acknowledged (SoSE with limited authority/control)

Assumptions and constraints

- All constituent systems exist and have their own evolutionary paths
- Model assumes SoSE and SE teams use relatively mature processes
- SoS capabilities are software-intensive
- No SoS capability/requirements volatility
- SoS internal volatility represented by constituent system volatility
- Does not address schedule or the asynchronous system upgrades
- Management of SoS internal interfaces reduces complexity for systems

Cost Driver:
Systems Engineering Requirements

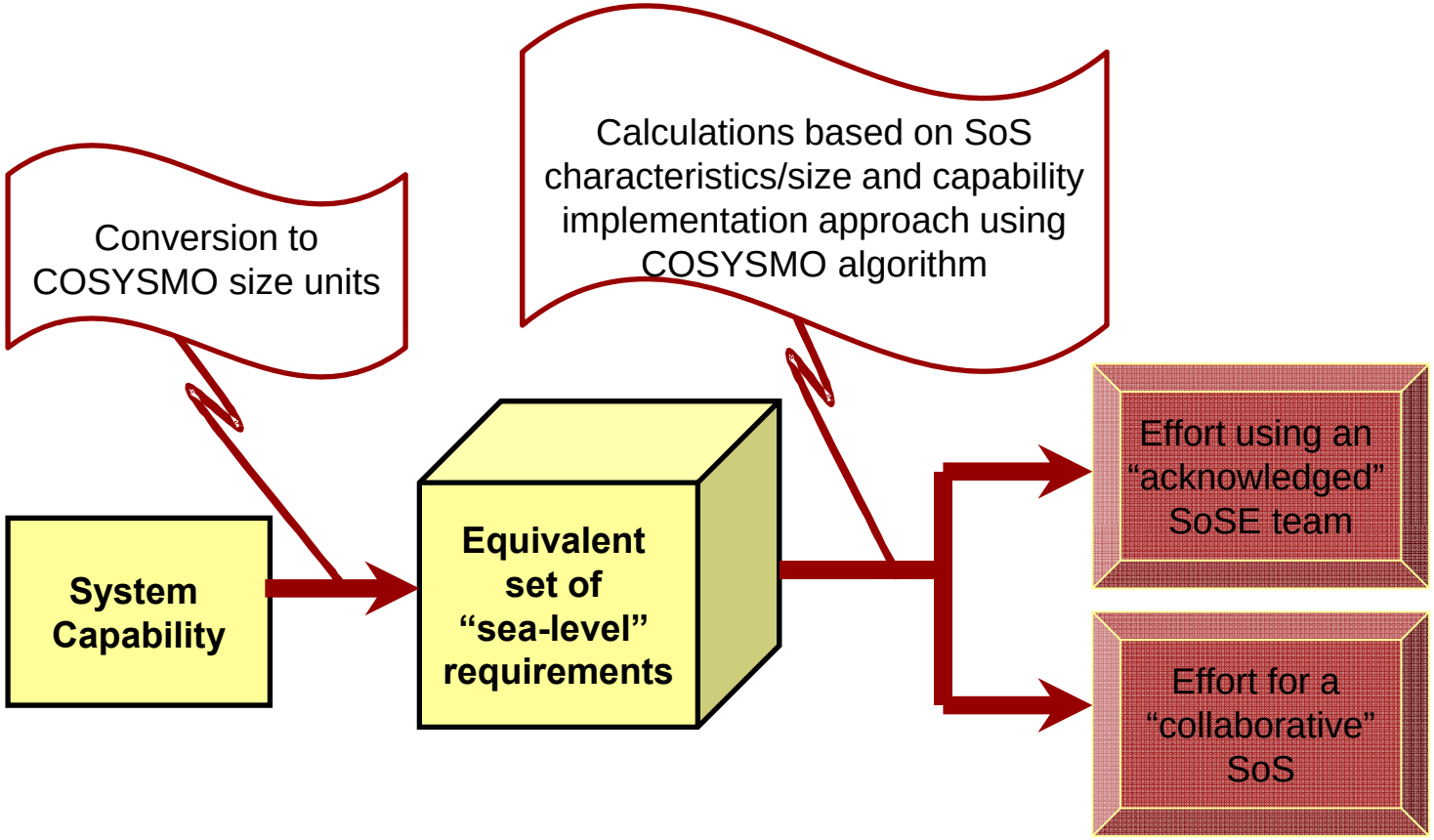
Requirements related to SoS capabilities

- *Acknowledged SoS:* Initially engineered at SoS level by SoSE team, then allocated to constituent systems for further SE
- *Collaborative SoS:* Engineered a the system level through collaborative efforts with other constituent system engineers

Non-SoS requirements related to constituent system stakeholder needs

- Must be monitored by SoSE team
- Represents on-going volatility at the constituent system level

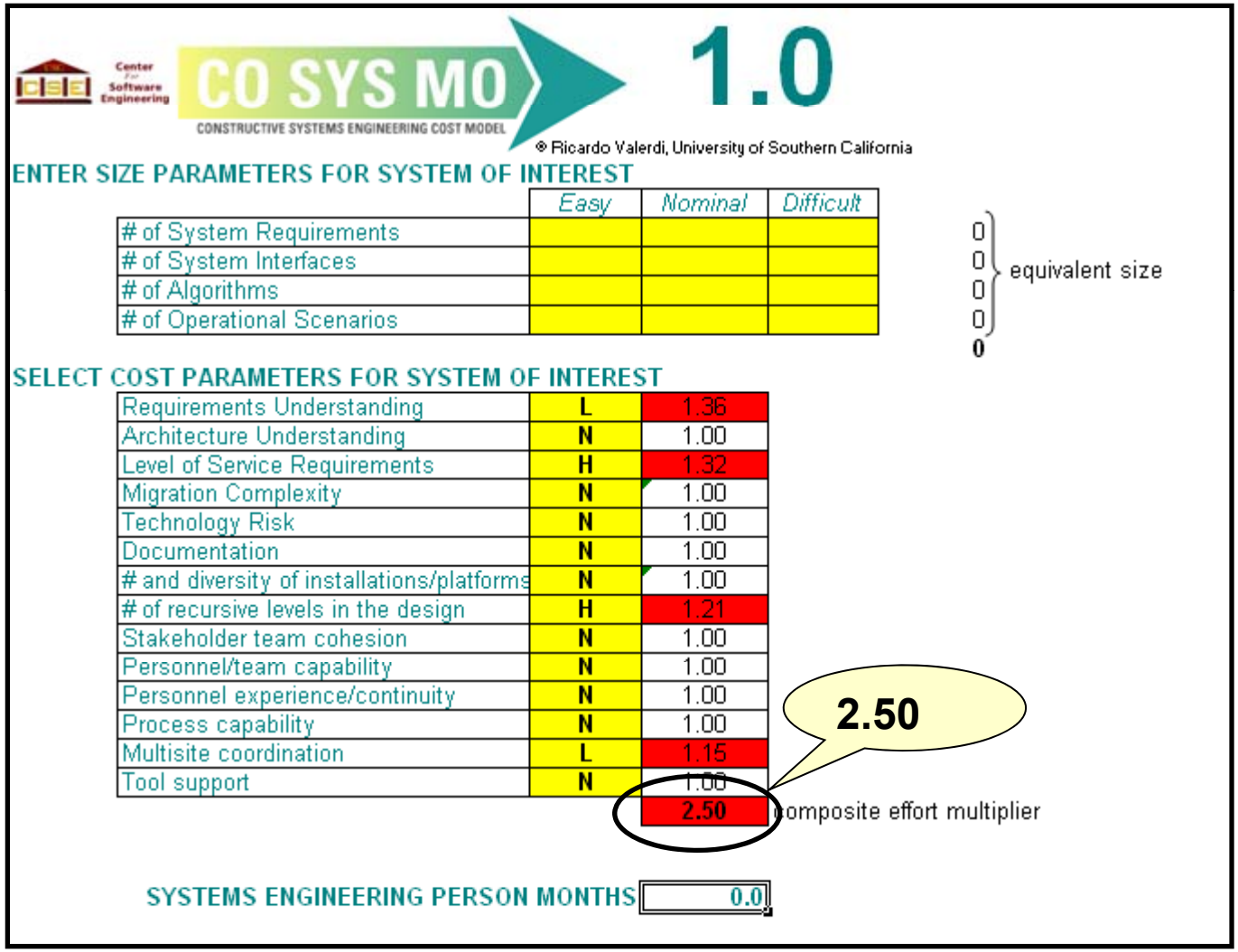
Overview of SoSE Model Flow



General Form of academic COSYSMO Equation

Effort (person months) = [38.55 * EM * (size)$^{1.06}$] / 152

COSYSMO and SoSE Effort Multiplier



CO SYS MO 1.0

CONSTRUCTIVE SYSTEMS ENGINEERING COST MODEL

© Ricardo Valerdi, University of Southern California

ENTER SIZE PARAMETERS FOR SYSTEM OF INTEREST

	Easy	*Nominal*	*Difficult*
# of System Requirements			
# of System Interfaces			
# of Algorithms			
# of Operational Scenarios			

0
0
0
0
0 equivalent size

SELECT COST PARAMETERS FOR SYSTEM OF INTEREST

Requirements Understanding	L	1.36
Architecture Understanding	N	1.00
Level of Service Requirements	H	1.32
Migration Complexity	N	1.00
Technology Risk	N	1.00
Documentation	N	1.00
# and diversity of installations/platforms	N	1.00
# of recursive levels in the design	H	1.21
Stakeholder team cohesion	N	1.00
Personnel/team capability	N	1.00
Personnel experience/continuity	N	1.00
Process capability	N	1.00
Multisite coordination	L	1.15
Tool support	N	1.00
		2.50 composite effort multiplier

2.50

SYSTEMS ENGINEERING PERSON MONTHS 0.0

Key SoSE Characteristics Used to Develop SoS Sub-Models

SoSE sub-model

- SoSE oversight of constituents can be characterized by using the appropriate COSYSMO reuse factor
- Other non-traditional SE activities performed by SoSE team can be handled through COSYSMO cost factors
- Two types of requirements (SoS and constituent system non-SoS requirements) modeled together using different effort multipliers*

Constituent system sub-model

- Each system within the SoS is independently owned and managed
- Constituent system SE effort to support the SoSE team can be characterized by including extra design effort for the SoS requirements
- Two types of requirements (SoS and constituent system non-SoS requirements) modeled together using different effort multipliers*

Use of multiple effort multipliers allows one to model the diseconomy of scale as the SoS becomes larger through the integration of components with different characteristics....

Summary of Effort Calculations

Effort Category	Key Requirements Sets	Extensions to COSYSMO
SoSE effort	1. SoS capability requirements 2. CS non-SoS changes to be monitored	1. Multiple EMs for different requirement sets 2. "Oversight" factor based on COSYSMO reuse factors
CS effort <u>with</u> SoSE support	1. Allocated SoS capability requirements (with SoSE support) 2. CS non-SoS changes	1. Multiple EMs for different requirement sets 2. System design "tax" to support SoSE team capability option analysis
CS effort <u>without</u> SoSE support	1. SoS capability requirements 2. CS non-SoS changes	1. Multiple EMs for different requirement sets

General Form of COSYSMO Equation

Effort (person months) = [38.55 * EM * $(\text{size})^{1.06}$] / 152

Summary of Model Effort Multipliers

EM	Value*	Modified Cost Parameters
SoSE effort	2.50	Requirements understanding (low) Level of service requirements (high) # of recursive levels in the design (high) Multisite coordination (low)
SoSE monitoring of CS Reqs	0.47	Technology risk (very low) Documentation (very low) Personnel/team capability (high)
Capability SE at CS level with SoSE Support	1.06	Architecture understanding (high) Level of service requirements (high)
Capability SE at CS level without SoSE Support	1.79	Requirements understanding (low) Level of service requirements (high)
SE of non-SoS reqs	0.72	Architecture understanding (high) # of recursive levels in the design (low)

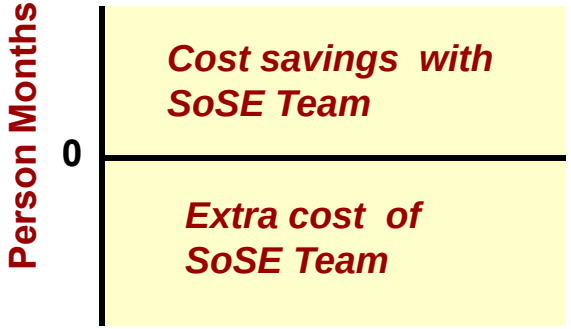
* Default value: 1.0 (all cost parameters set to nominal)

Range of SoS Complexity Factor Values

SoSE Model Parameter	Description	Range of Values
SoS Size	Number of constituent systems within the SoS	2-200
SoS Capability Size	Number of equivalent nominal requirements as defined by COSYSMO	1-1000
Constituent System Volatility	Number of non-SoS changes being implemented in each constituent system in parallel with SoS capability changes	0-2000
Scope of SoS Capability	Number of constituent systems that must be changed to support capability	One to SoS Size (all)
SoSE Oversight Factor	Oversight adjustment factor to capture SoSE effort associated with monitoring constituent system non-SoS changes	5%, 10%, and 15%

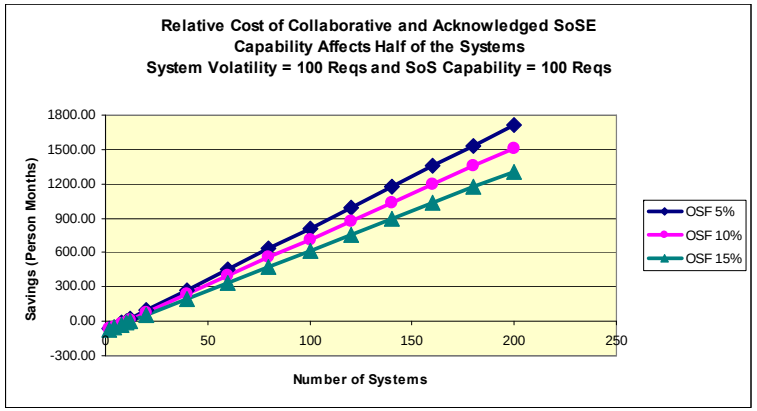
Model Results

Each graph shows for each OSF value:
(SoSE effort + ∑Acknowledged CS_i effort*) – (∑Collaborative CS_i effort *)

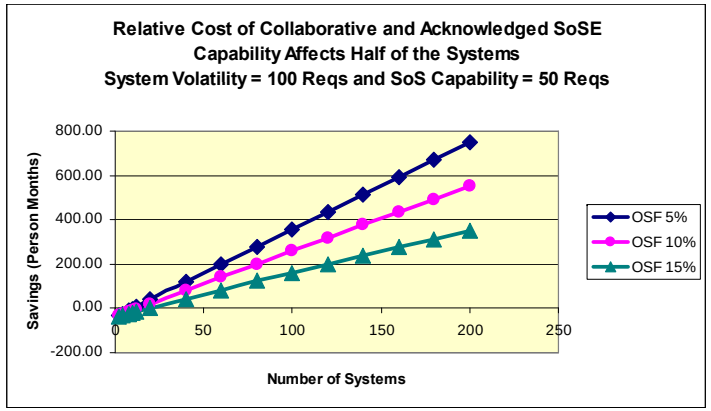


* CS effort is the sum of the SoS capability effort and the non-SoS requirements effort

Scenario 1 (SoS Size Varies)

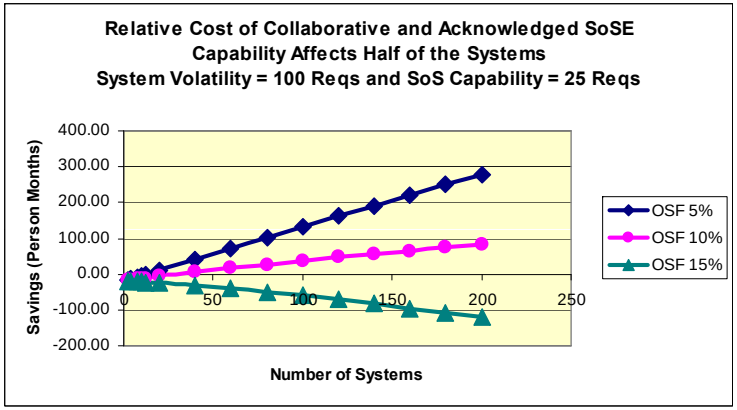


Scenario 2 (SoS Size Varies)

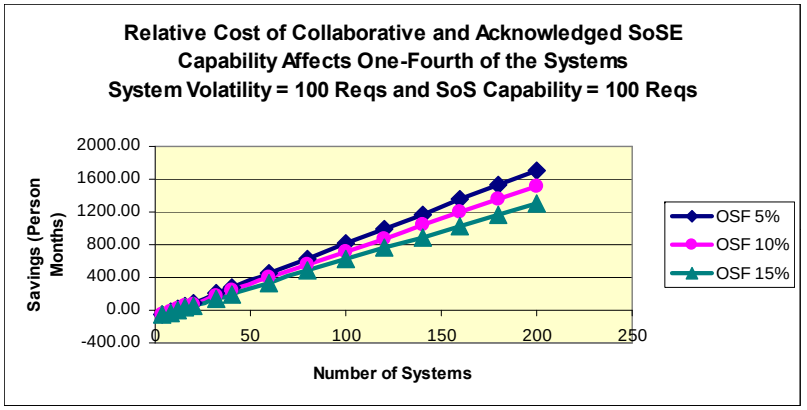


Model Results *(continued)*

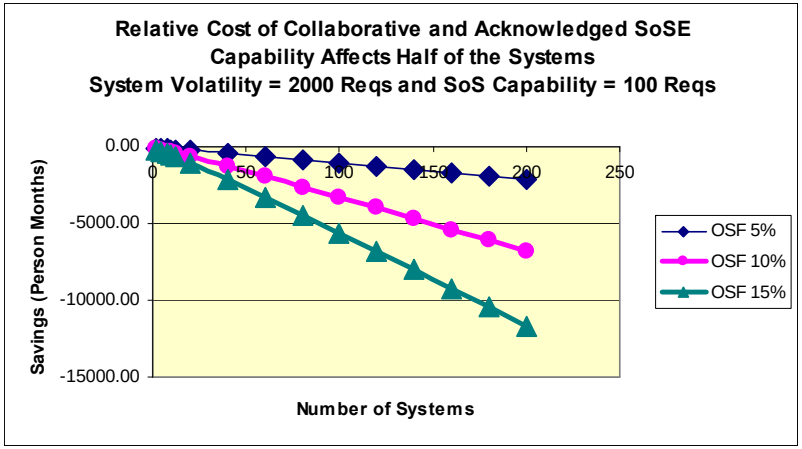
Scenario 3 (SoS Size Varies)



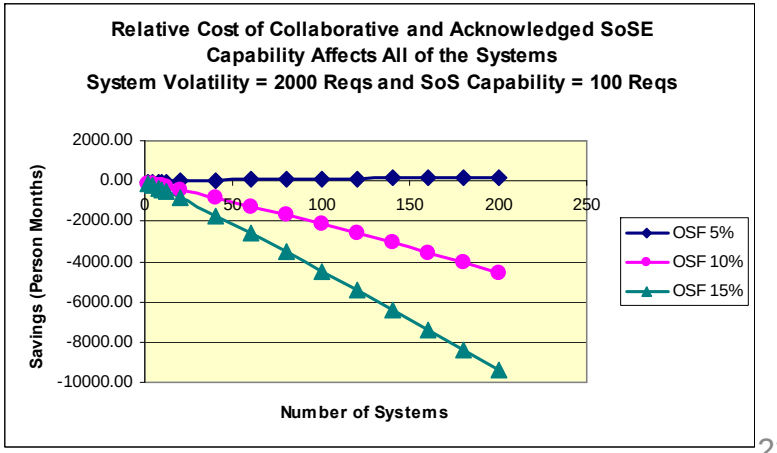
Scenario 4 (SoS Size Varies)



Scenario 5 (SoS Size Varies)

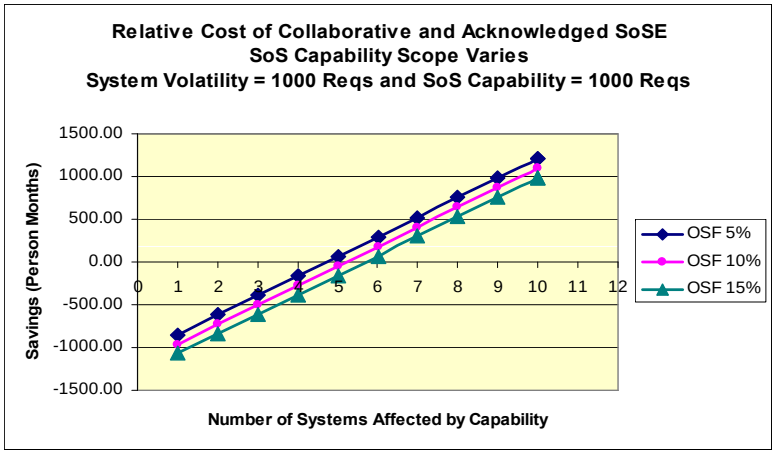


Scenario 6 (SoS Size Varies)

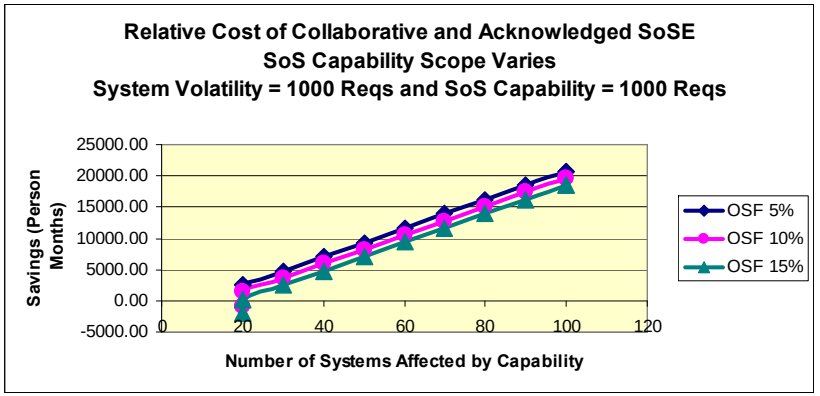


Model Results *(continued)*

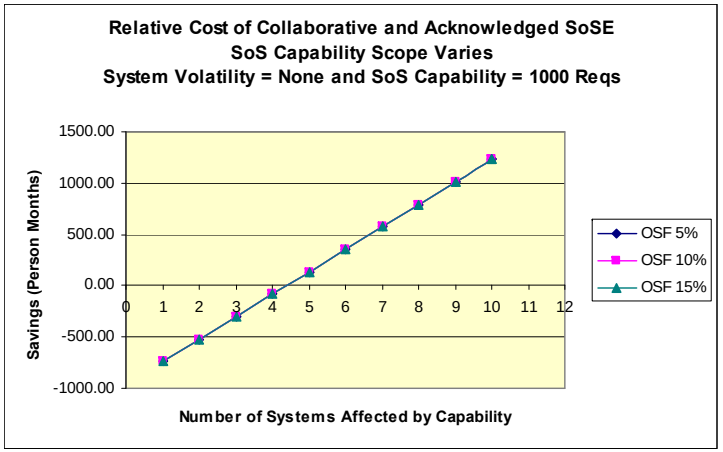
Scenario 7-a (SoS Size = 10)



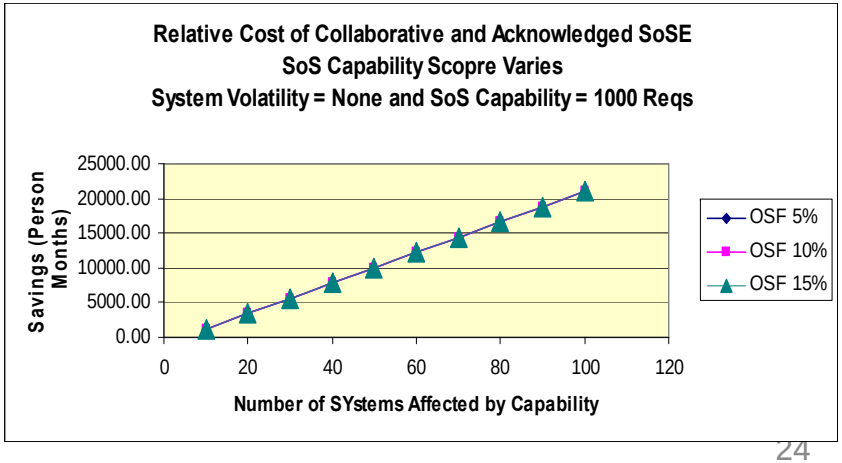
Scenario 7-b (SoS Size = 100)



Scenario 8-a (SoS Size = 10)

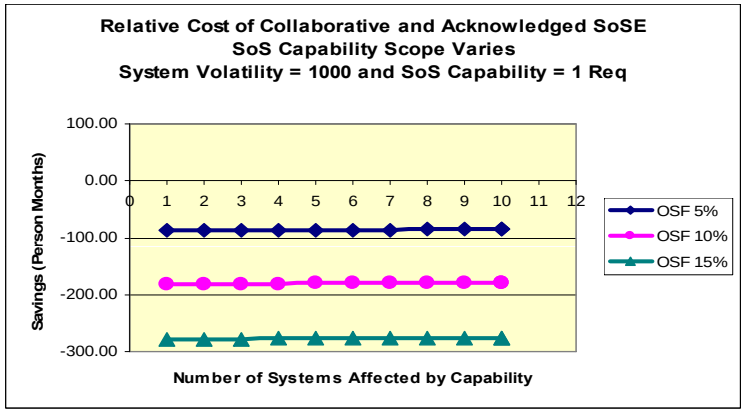


Scenario 8-b (SoS Size = 100)

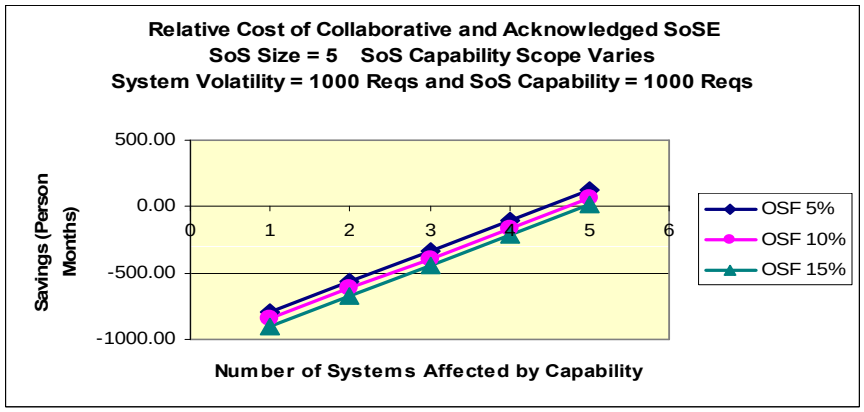


Model Results *(continued)*

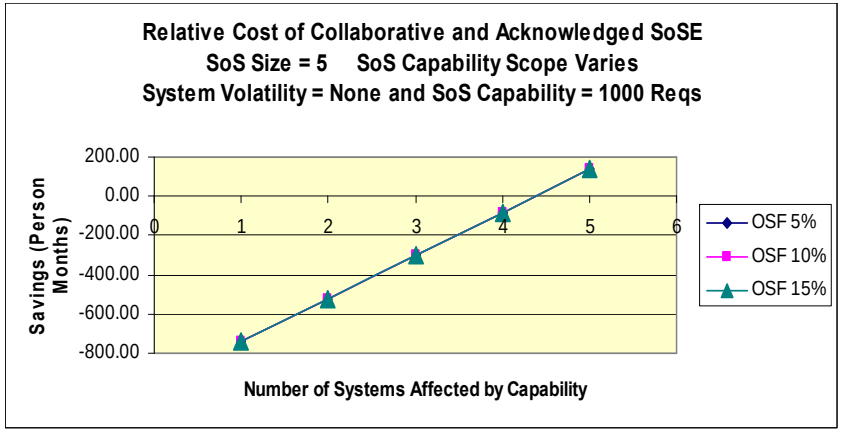
Scenario 9 (SoS Size = 10)



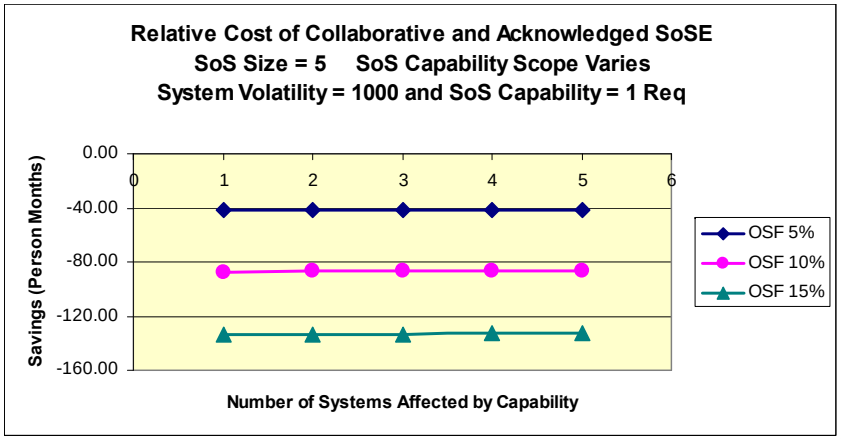
Scenario 10 (SoS Size = 5)



Scenario 11 (SoS Size = 5)



Scenario 12 (SoS Size = 5)



SoSE Cost Model Summary

SoSE cost model based on COSYSMO can provide

- Guidance to DoD leadership with respect to management structure
- A method for conducting capability trade-off analyses
- A model that can evolve into an SoSE cost model for a specific SoS
- A cost model that can better model complex systems

Guidance also applies to SoSs in other domains that are managed as collaborative or acknowledged SoSs

Key is local calibration of SoSE cost model

SoS Management Conclusions

SoSE team is cost effective when

- SoS contains more than a “few” systems
- SoS capability changes typically affect a “significant percentage” of CSs
- SoS capability requirements are a “significant percentage” of the total reqs addressed by CSs in an upgrade cycle
- SoS oversight activities and the rate of capability modifications/changes being implemented are sufficient to keep an SoSE team engaged (i.e., little-to-no slack time)

SoSE team is NOT cost effective when

- The number of systems in an SoS is “small”
- The CS volatility is high and the SoS changes are small

SoS Management Conclusions *(continued)*

The SoSE "oversight factor" is a key factor in determining the cost effectiveness of the SoSE team

- More work is needed to determine a more accurate "oversight factor"
- This factor may be variable across multiple SoSs

There may be reasons other than cost to engage an SoSE team

- Importance of SoS
- Critical SoS performance requirements requiring extensive analysis at the SoS level

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